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(54) VCSEL AND VCSEL ARRAY HAVING INTEGRATED MICROLENSES FOR USE IN A SEMICONDUCTOR LASER PUMPED SOLID STATE LASER SYSTEM

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(52) **U.S. Cl.** **372/75**; 372/36; 372/69; 372/70

(58) **Field of Search** 372/36, 69, 70, 372/75

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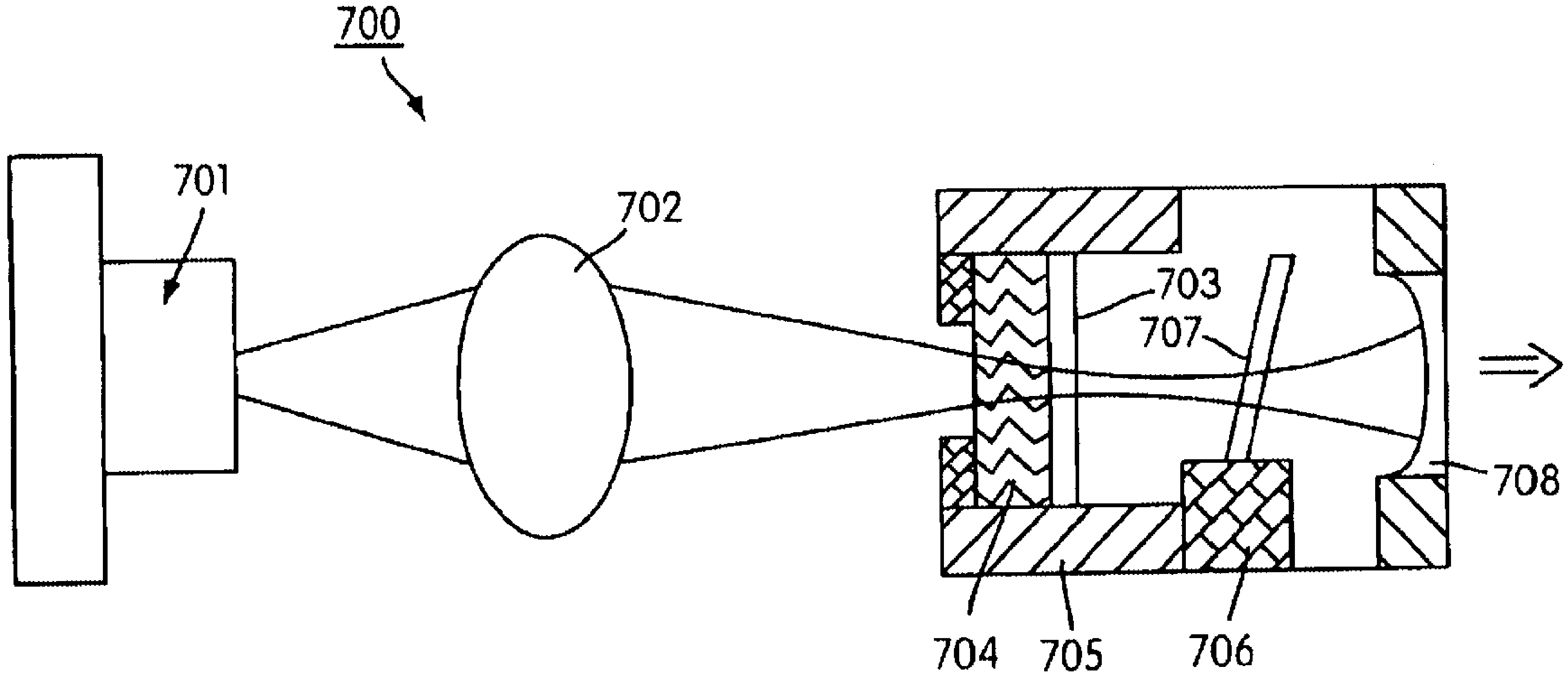
(57) ABSTRACT

A vertical cavity surface emitting laser (VCSEL) device with improved power and beam characteristics. The VCSEL device contains one VCSEL or an array of VCSELs. Each VCSEL has a corresponding integrated microlens, and a heat sink is attached to the device side of the VCSEL device. The heat sink allows improved heat dissipation, and therefore provides improved power characteristics of the VCSEL device output laser beam. The microlens or microlens array allows easier and more compact focussing of the VCSEL device output laser beam. The VCSEL device can be used in a variety of optical systems, and its improved power and focusing characteristics provide a compact, low power, low cost laser system.

20 Claims, 5 Drawing Sheets



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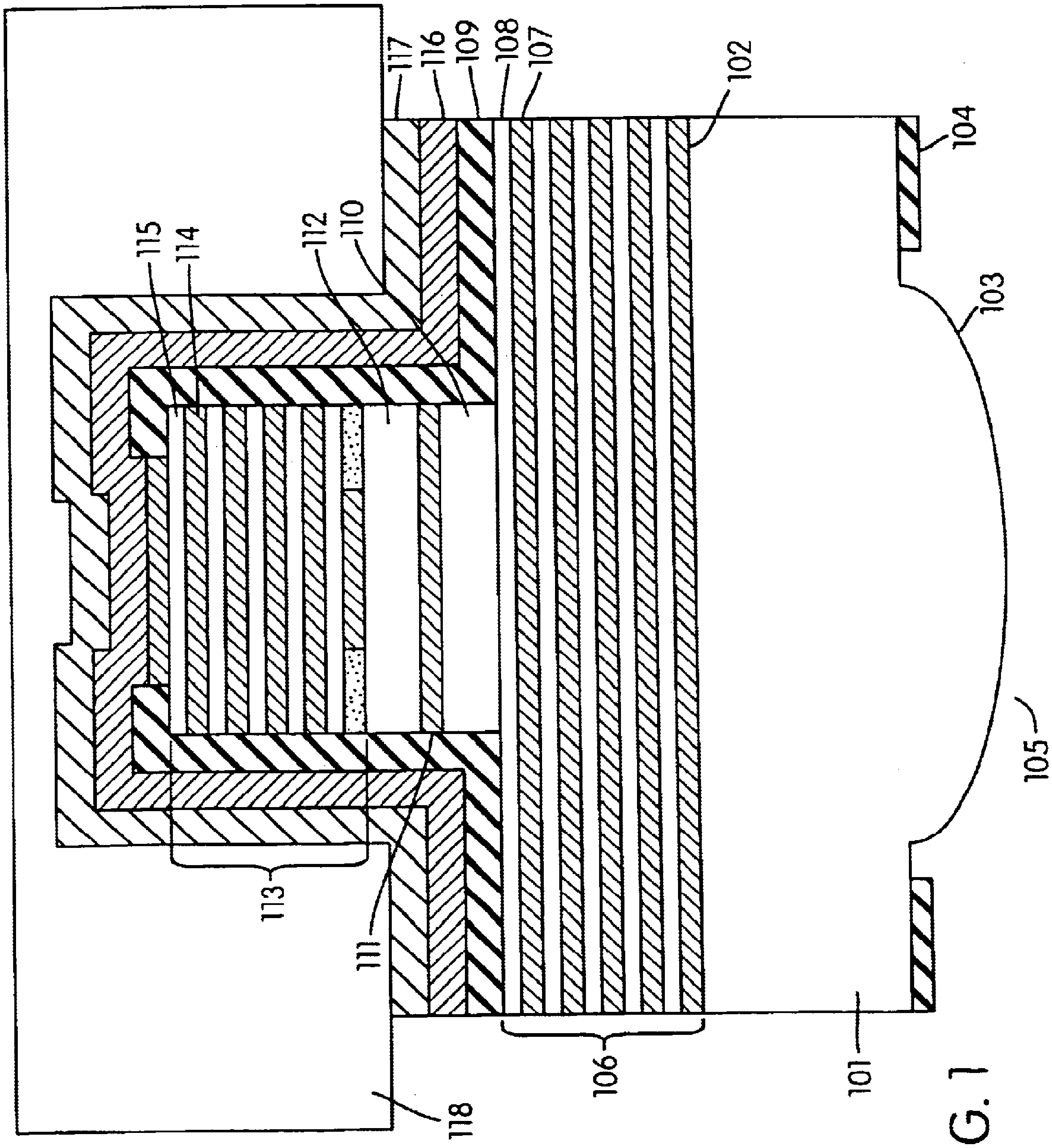
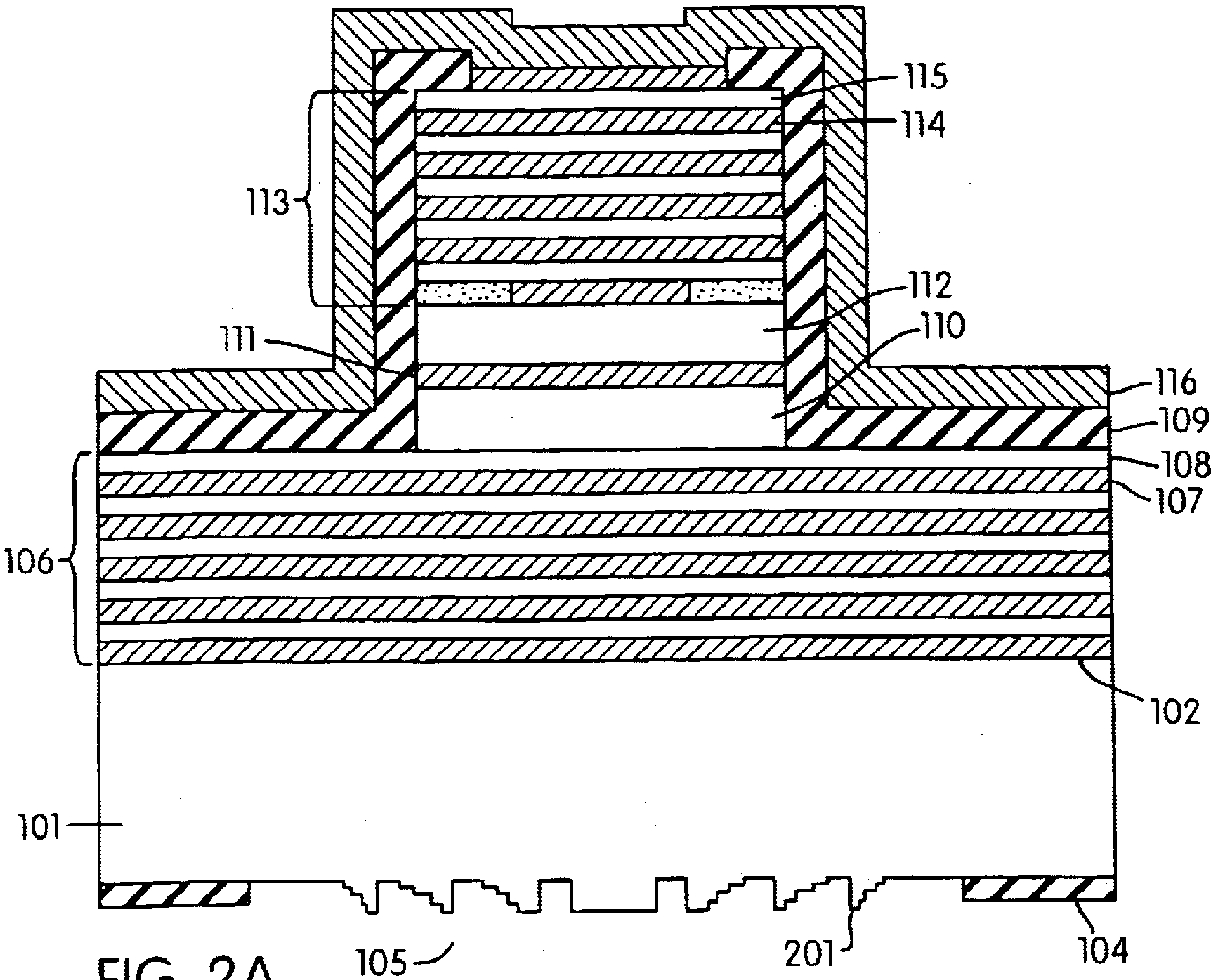

117
116
109
108
107
102
104
115
114
112
110
103
105
113
111
106
101
118

FIG. 1


115
114
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111
116
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108
107
106
102
101
105
201
104

FIG. 2A

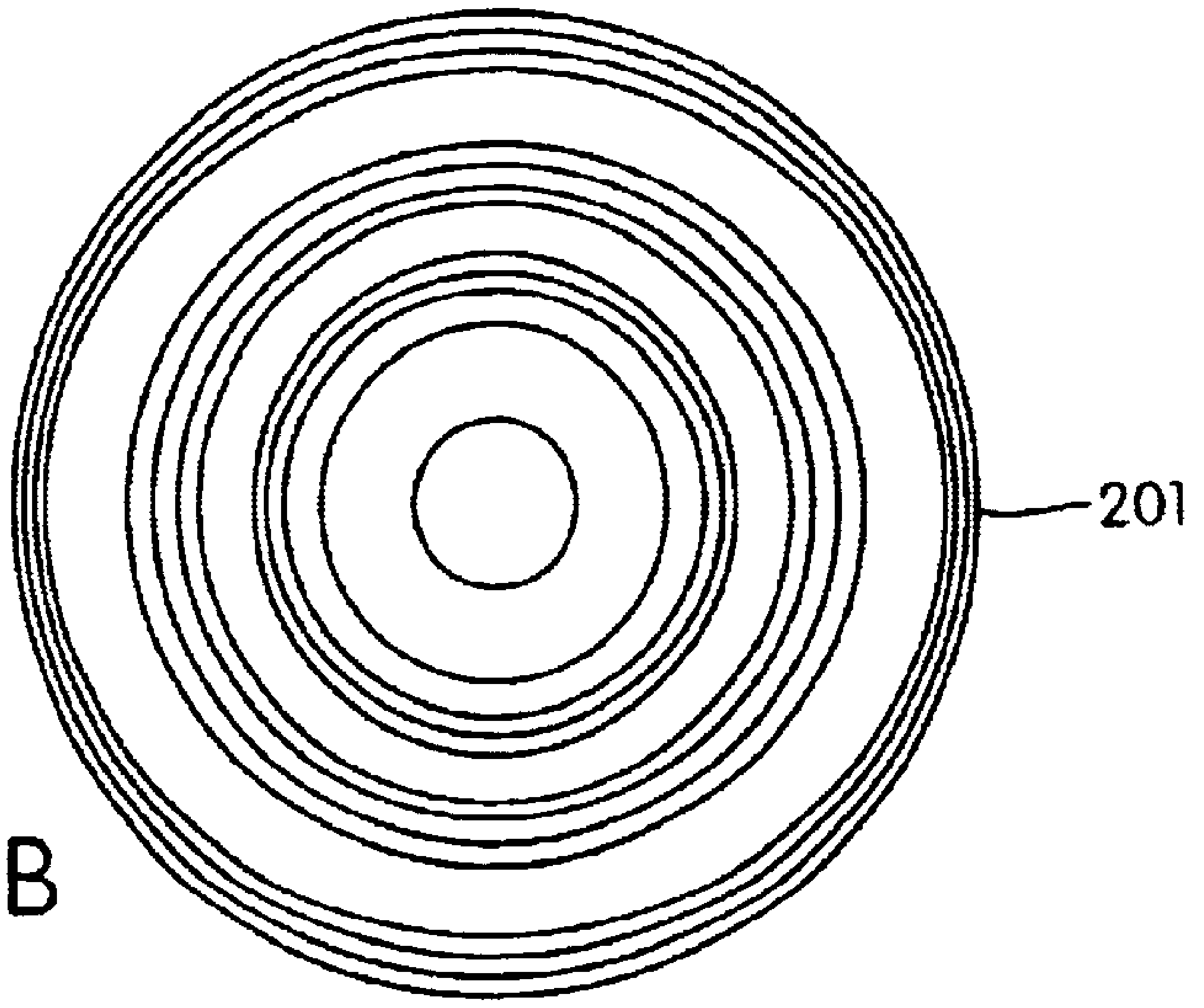
201

FIG. 2B

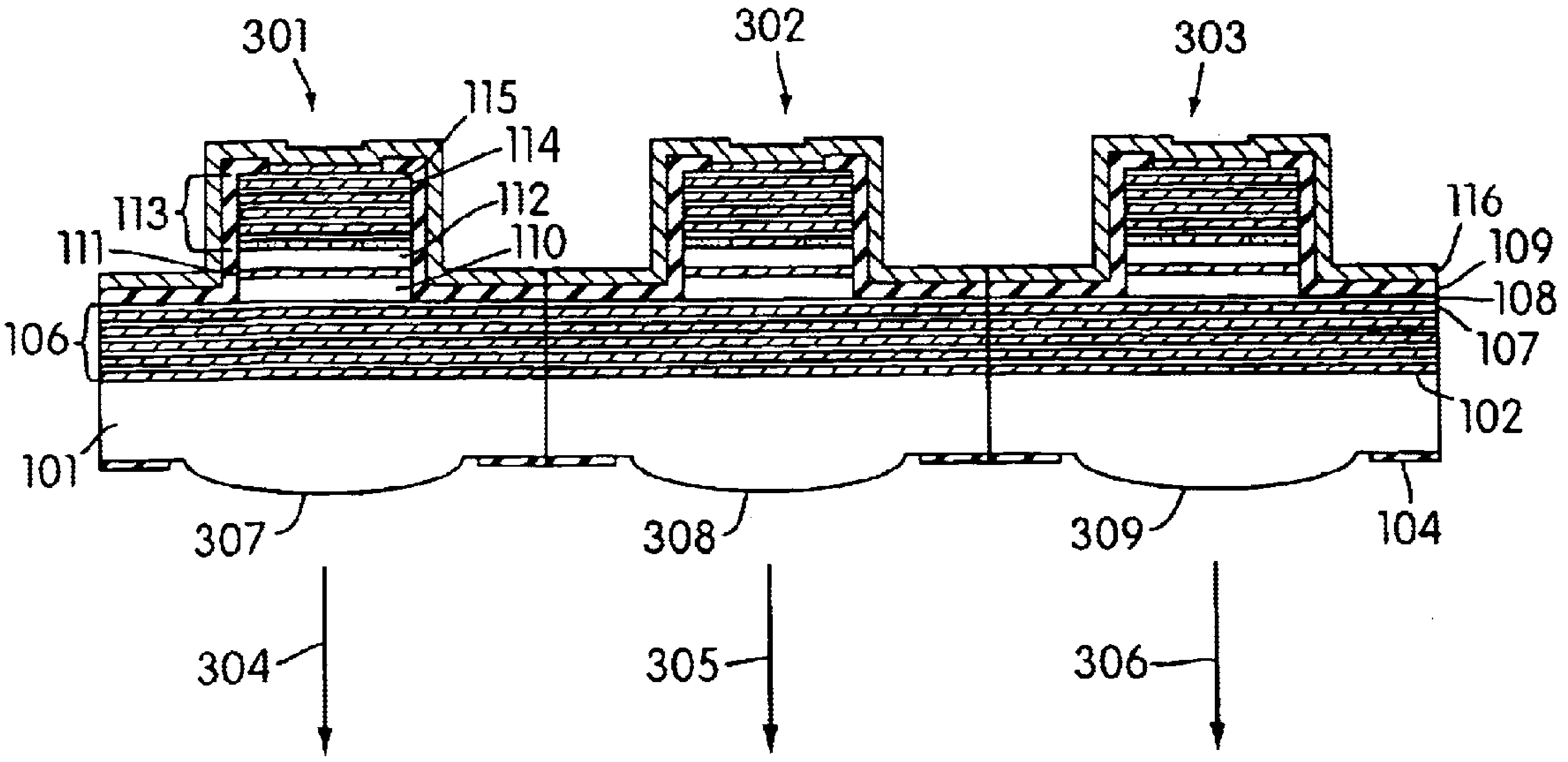
301
302
303
115
114
113
112
111
110
116
109
108
107
106
102
101
104
307
308
309
304
305
306

FIG. 3

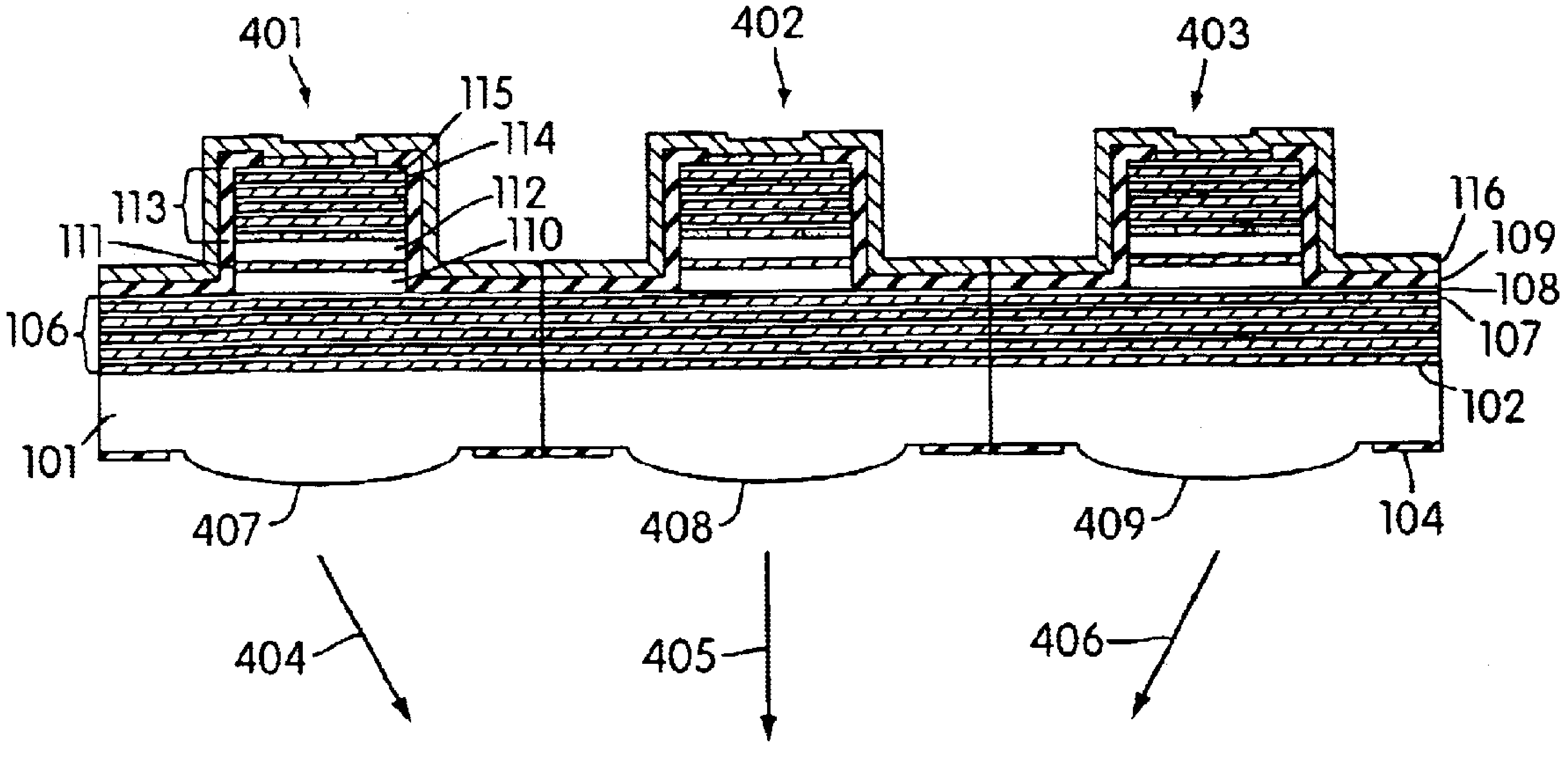
401
402
403
115
114
113
112
111
110
116
109
108
107
106
102
101
104
407
408
409
404
405
406

FIG. 4

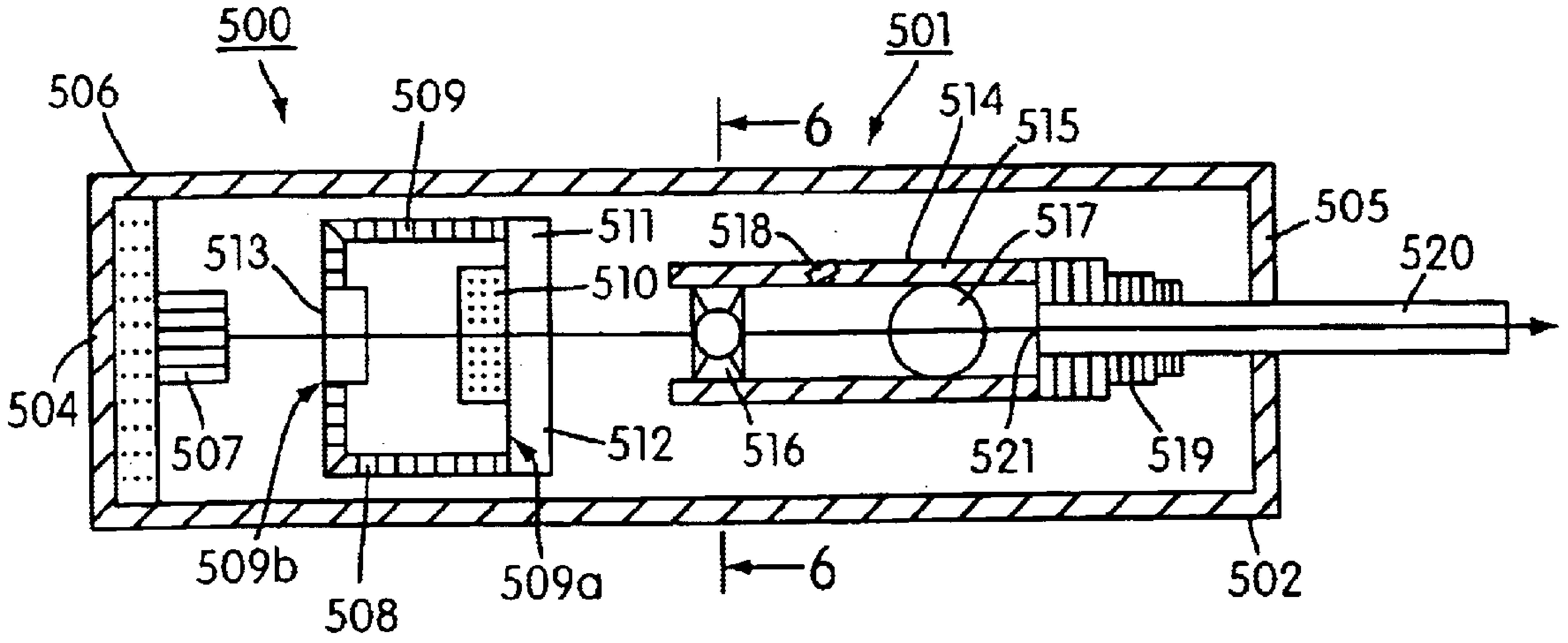
500
501
506
509
6
514
515
505
520
513
511
518
517
510
504
507
512
516
521
519
509b
508
509a
6
502

FIG. 5

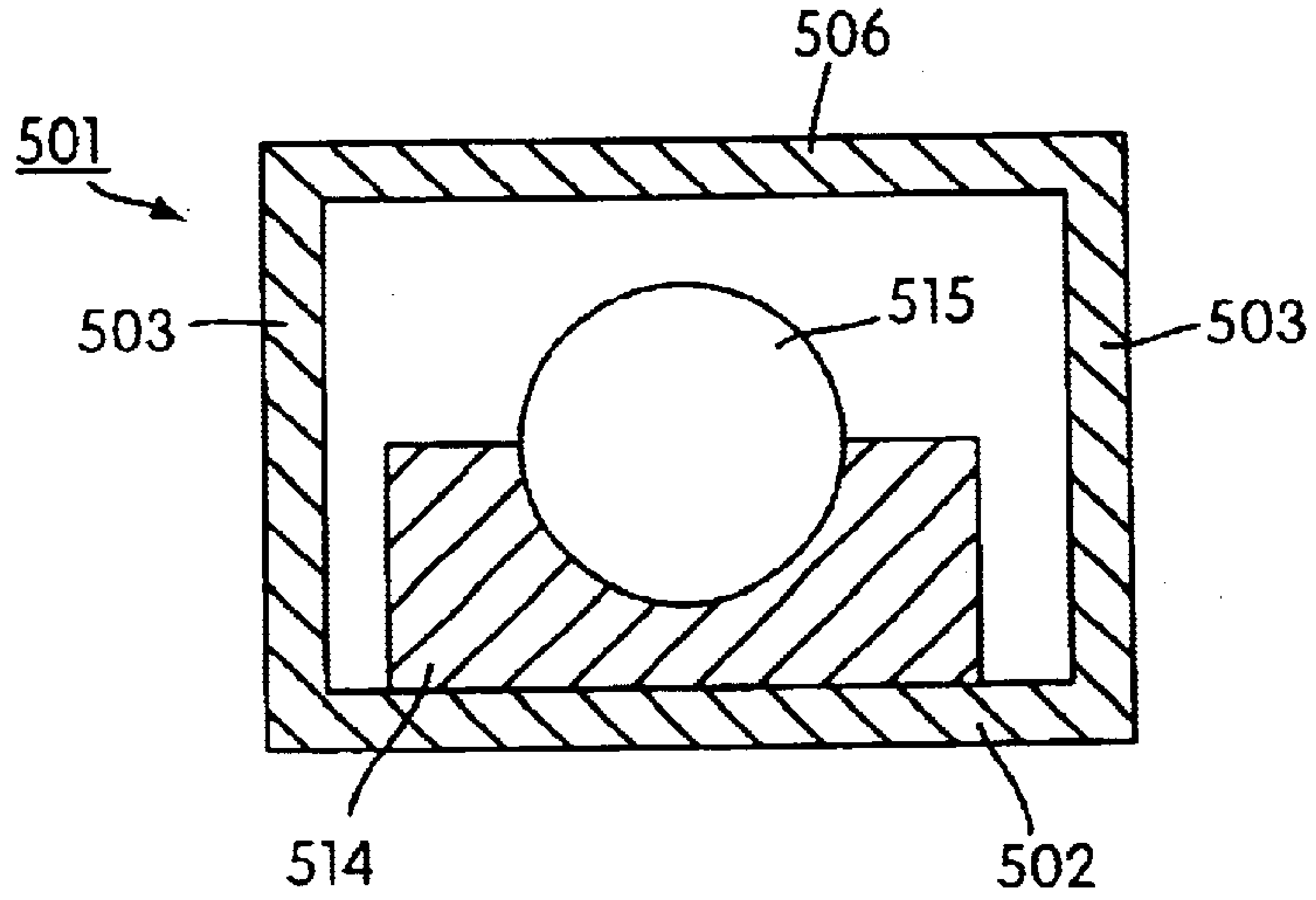
506
501
503
515
503
514
502

FIG. 6

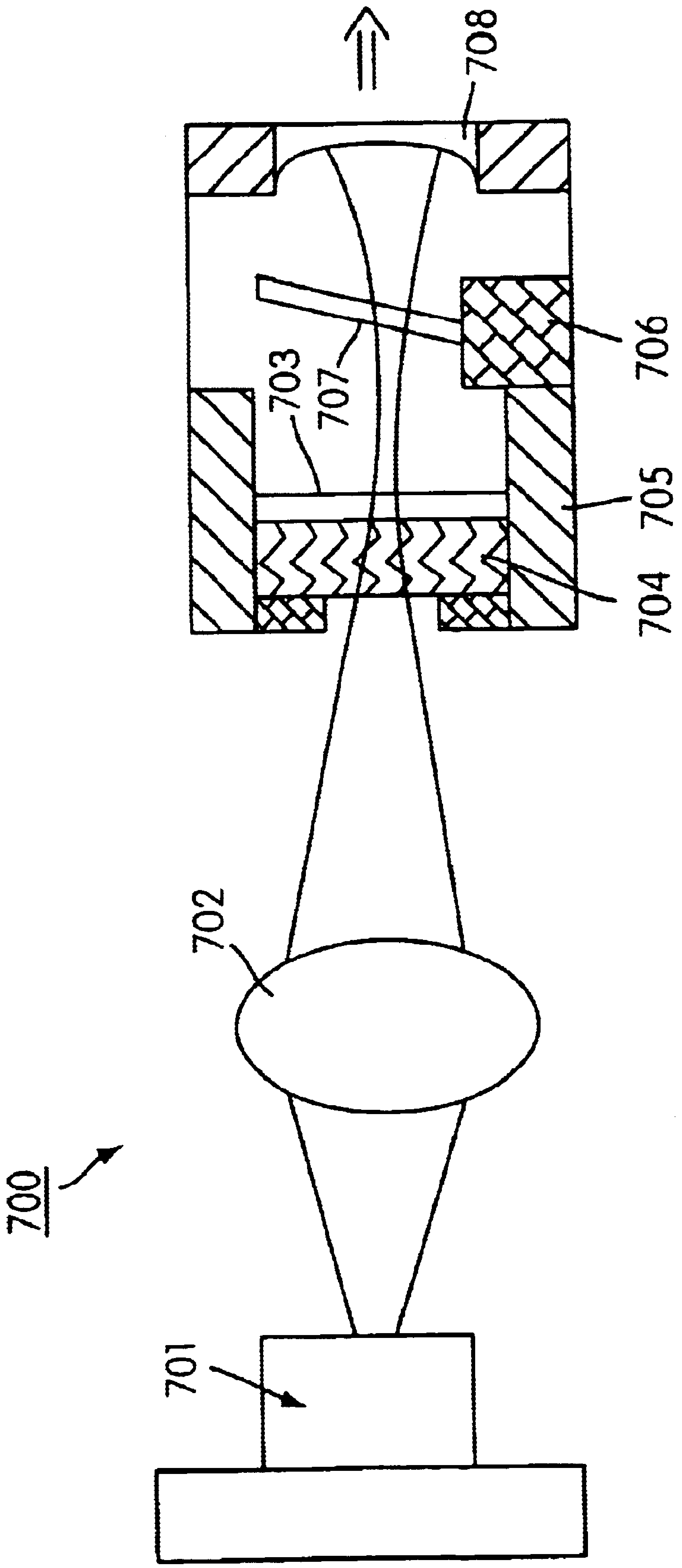

FIG. 7

VCSEL AND VCSEL ARRAY HAVING INTEGRATED MICROLENSES FOR USE IN A SEMICONDUCTOR LASER PUMPED SOLID STATE LASER SYSTEM

FIELD OF THE INVENTION

The present invention relates to a vertical cavity surface emitting laser (VCSEL) having a device-side heat sink and integrated microlenses. Such a VCSEL can be advantageously used in a variety of communications systems, including a semiconductor laser pumped solid state laser system, and, more particularly, a light generating and emitting system for telecommunications and data communications applications in which a solid state laser is pumped by a VCSEL.

BACKGROUND OF THE INVENTION

Compact, low-cost and low-noise lasers are critical for the development of high performance analog photonics systems, such as fiber optic transmission systems. However, such lasers have not yet been satisfactorily developed.

For example, the use of externally-pumped solid state lasers to produce laser beams for fiber optic transmission is well-known. Such laser systems might include Er:Yb-doped glass microchip lasers, which are particularly useful for generating light beams having appropriate wavelengths for optical communications systems (i.e., 1530–1560 nm). However, such laser systems typically require the use of expensive or inefficient pumping mechanisms, such as flash lamps.

Diode lasers are known to be a relatively inexpensive and efficient pumping mechanism; however, such lasers are typically too low in power and beam quality to be effective in a wide range of applications. In particular, low-power vertical cavity surface emitting lasers (VCSELs), having a power output of approximately 2–5 mW, are known to be inexpensive and easy to produce. Moreover, VCSELs are well-suited for certain fiber optic applications, e.g., low-power transmissions over multimode fibers, due to the ease of matching the light emitted from the circular emitting facet of a VCSEL to a similarly-shaped core of a fiber optic cable.

However, conventional VCSELS, like edge-emitting diode lasers, are too low in power to effectively serve as a pumping mechanism for a doped-glass laser such as the Er:Yb laser referred to above. Moreover, output power of a single VCSEL cannot be increased effectively by increasing the size of the surface area of its emitting facet, due to poor heat dissipation properties of such a VCSEL. It is known to overcome this shortcoming by arranging multiple VCSELs into an array and including a heat sink attached to the device side of these VCSELs (as opposed to the substrate side). However, such high-power arrays of VCSELS were contemplated only in the context of optical ignition mechanisms. Finally, conventional laser systems including VCSEL devices typically require extensive use of external, discrete lens systems for effective utilization of the VCSEL output beams. The need to include and arrange such lens systems is responsible for an increase in system size and cost.

SUMMARY OF THE INVENTION

A VCSEL according to an embodiment of the present invention is a bottom-emitting VCSEL which achieves a high power output by including a heat sink on the device side, rather than on the substrate side, to thereby allow for improved heat dissipation. A plurality of these VCSELs can be arranged into an array, to further increase the total power output. In addition, refractive microlenses are integrated with the substrate of the VCSEL or VCSELs, and are used to decrease the divergence of the output beam(s), as well as to assist in focusing and/or collimating the beam(s) for a variety of communication applications. Thus, the need for costly and space-consuming external lenses is reduced.

The resultant VCSEL device can be compact and inexpensive, and yet produce a high-power, high quality output beam which can be effectively coupled to external optical elements.

The VCSEL device according to the present invention, and particularly the VCSEL device array according to the present invention, can advantageously be used as a pumping mechanism for a doped-glass laser, such as an Er:Yb-doped glass laser, to thereby provide a compact, low-cost, low-noise, high-power laser system.

The Er:Yb glass laser can also be used as the gain medium for a tunable laser, and the laser system according to the present invention, whether single-frequency or tunable, can be used in a wide variety of optical communication applications.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view of a single VCSEL device used in the present invention and having an integrated refractive microlens;

FIG. **2A** is a sectional view of a single VCSEL device used in the present invention and having an integrated diffractive microlens for focussing the beam emitted by the VCSEL device;

FIG. **2B** is a bottom view of the VCSEL device shown in FIG. **2A**;

FIG. **3** is a sectional view of a typical VCSEL array which can be used in the device of the present invention and which contains integrated refractive microlenses for parallel beam output;

FIG. **4** is a sectional view of the array of VCSEL devices as shown in FIG. **3** and containing integrated refractive microlenses for convergent beam output.

FIG. **5** is a top view of the optical device of the present invention with the cover of the housing removed;

FIG. **6** is a sectional view taken along line **6**—**6** of FIG. **5**;

FIG. **7** is a schematic drawing of a tunable laser system according to the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. **1** demonstrates an exemplary embodiment of VCSEL **100** according to the present invention. VCSEL **100** comprises a substrate **101** of a suitable semiconductor material, on which the other materials of the VCSEL **100** can be grown, such as GaAs, Si, InP or the like. The substrate **101** has opposed inner and outer surfaces **102** and **103**, and is preferably of N-type conductivity. N-ohmic contact layer **104** is deposited onto surface **103** and defines a region **105** through which light is emitted, as described below. Region **105** is coated with an antireflecting dielectric layer (not shown). On the inner surface **102** of the substrate **101** is a first mirror stack **106**. The mirror stack **106** is a distributed Bragg reflector, and is formed of alternate layers **107** and **108** of semiconductor materials having different indices of refraction. This is achieved, for example, by using materials of different compositions, such as AlGaAs, in which the amount of aluminum in the material of the layers **107** is different from the amount of aluminum in the material of the layers **108**. As is well known, the thickness and the specific compositions of the layers **107** and **108** determines the wavelength of the light emitted by the VCSEL. The material of the layers **107** and **108** of the first mirror stack **106** are of, for example, N-type conductivity.

On the first mirror stack **106** are insulator **109**, which extends up and around the active layer **111**, second mirror stack **113** of the VCSEL (described in detail below), and cladding **110**, which, together with a second cladding layer **112**, sandwiches active region **111**. The active region **111** is undoped. The active region **111** may be of a well-known quantum well structure, or a multi-quantum well structure. The thickness of the active region may be, for example, half of the emitting wavelength or one emitting wavelength.

A second mirror stack **113** is above the active layer **111**. The second mirror stack **113** is also a distributed Bragg reflector and, like the first mirror stack **106**, comprises alternating layers **114** and **115** of materials having different indices of refraction. The layers **114** and **115** of the second mirror stack **113** may be of the same materials as those of the layers **107** and **108** of the first mirror stack **106**. However, the layers **114** and **115** of the second mirror stack **113** are of an opposite conductivity to the layers **107** and **108** of the first mirror stack **106**; e.g., here, layers **114** and **115** are of P-type conductivity. A contact layer **116** of a conductive material, such as a metal, is coated on the second mirror stack **113**.

A heat sink body **118** of a disc of a thermally conductive material, such as diamond or a metal, is mounted on the contact layer **116** by a suitable bonding material **117**, such as solder. Conventional VCSEL devices typically include heat sinks; however, these heat sinks are mounted on the substrate side of the VCSEL. Because of the thickness of the substrate (typically over 100 microns), heat from the VCSEL does not dissipate well. In contrast, the heat sink body **118** of the present invention removes heat more directly from the semiconductor materials of the VCSEL, and is therefore much more effective in preventing excessive heating of the VCSEL. This allows the VCSEL to be operated at significantly higher powers, in the range of at least 50–100 mW.

Additionally, outer surface **103** of the substrate **101** can be formed into a curved surface, for example, by chemical etching. This curved surface **103** forms a microlens for the light beam emitted by the VCSEL through the light-emitting window **105**. For the single VCSEL device shown in FIG. **1**, the microlens can reduce the beam divergence of the laser beam emitted from the VCSEL. Without this microlens, beam divergence of the VCSEL device would be approximately 10–15 degrees. However, the microlens of the present invention reduces beam divergence to approximately 0–1 degrees, and thereby allows for a smaller spot size, easier coupling to a fiber optic cable for transmission therethrough, etc. For certain applications, such as coupling for multimode fiber optic transmission, the above-described arrangement, including a microlens, can suffice, without any need for an external lens arrangement.

Alternatively, as shown in FIGS. **2**A and **2**B (wherein like reference numerals refer to like parts shown in FIG. **1**; also, note that bonding material **117** and heat sink **118** are not shown in FIGS. **2**–**4**), the outer surface of the substrate **101** can be etched to form step surfaces **201** forming concentric circles, thereby providing a diffractive microlens. Such a microlens also allows direct focusing of the output beam of the VCSEL.

As shown in FIG. **3**, a VCSEL array **300** may be formed using the VCSEL described in conjunction with FIG. **1** (wherein, again, like reference numerals refer to like parts shown in FIG. **1**). Thus, VCSEL devices **301**, **302** and **303** can be formed together as a VCSEL array, where each device respectively outputs beams of light **304**, **305** and **306**, to thereby cumulatively provide a VCSEL array output beam. Individual elements are formed by etching through the P-type layers, followed by dielectric passivation before the final interconnect metal layer is deposited for electrical contact. This forms an array of light emitting elements which are electrically biased in parallel through an N-type ohmic contact layer **104** on the substrate and a P-type ohmic contact layer **116** on the second mirror stack. A heat sink body, as shown in FIG. **1**, can be mounted and secured onto the contact layer **116**.

The outer surface **103** of the substrate **101** is formed into a plurality of individual microlenses **307**, **308**, **309** to form an array of the microlenses. A dielectric antireflecting coating layer (not shown) is deposited on the microlenses for efficient light emission. Light from each of the VCSEL devices of the array **300** will pass through a corresponding one of the separate microlenses **307**, **308**, **309**.

When viewed from below, the array as described above can be arranged in a variety of shapes and sizes; for example, circular, rectangular or hexagonal. The size of the VCSEL device as described above can be, for example, as large as 150–200 microns, and the array size can be 100 or more. An array size of 6×6 can easily provide a total power output of approximately 1W.

As shown in FIG. **3**, the refractive microlens array can be arranged to provide an output of parallel beams forming a composite beam. Thus, with a beam divergence of effectively <1 degree, focusing of these parallel beams (i.e., the composite beam) can then be easily achieved with a separate lens, if, for example, the array size is relatively large for a particular high-power application and additional focussing is needed, perhaps for coupling to a fiber optic cable having a relatively small numerical aperture. For a smaller power and array size, additional focussing might not be necessary, and so the beam(s) can be coupled directly into, for example, a wide-aperture, multimode fiber optic cable.

As shown in FIG. **4**, a refractive microlens array **400** having VCSEL devices **401**, **402**, **403** can be designed to result in an output of convergent beams **404**, **405**, **406** through microlenses **407**, **408**, **409**. This arrangement effectively reduces the beam divergence of the beam output by the VCSEL array as a whole, and thereby allows, if necessary, easier and more effective focusing by external lenses. Particularly, external lenses can be offset from the output axis of a corresponding VCSEL within the VCSEL array, toward the direction of the center of the array, to thereby (progressively) focus the output beam of the array as a whole more effectively. This arrangement is particularly useful for coupling the output beam of the VCSEL to a single mode fiber for telecommunications applications. Note that in both of FIGS. **3** and **4**, the vertical lines between VCSEL devices **301**–**303** and **401**–**403** are intended merely to illustrate conceptual separation points between the VCSEL devices, and are not intended to imply any literal or physical feature of the present invention.

A form of a laser system according to the present invention which makes use of the VCSEL and/or VCSEL array described above is generally designated in FIGS. **5** and **6** as **500**. Laser system **500** comprises a housing **501** of a good thermally conducting material, such as copper or kovar, having an approximately rectangular shape The housing **501** comprises a flat base plate **502**, and a pair of side walls **503** extending from the sides of the base plate **502**. The housing **501** has back and front end walls **504** and **505** at the ends of the base plate **502**. A cover **506** extends across and is secured to the side walls **503** and the end walls **504** and **505**. Within the housing **501** and mounted on the inner surface of the back end wall **504** is a VCSEL **507** (which might include, for example, the structures shown in FIGS. **1–14**). Note that the dimensions of a heat sink body **118** attached to VCSEL (array) **507** as described above (although not shown in FIG. **5**) are substantially the same as the inner dimensions of the outer wall of the housing **501** so that the heat sink body **118** fits tightly within the housing **501**.

Within the housing **501** and in front of the VCSEL **507** is a solid state microchip laser assembly **508**. The solid state microchip laser assembly **508** comprises a mounting block **509** of a good heat conducting material which fits into the housing **501**. The mounting block **509** has a recess **509***a* in its front surface and an opening **509***b* extending from the bottom of the recess **509***a* to the back of the mounting block **509**. A microchip laser **510** is within the recess **509***a* in the mounting block **509**. The microchip laser **510**, which might be made of, for example, an erbium and ytterbium doped glass, is mounted on a mounting plate **511** of optically transparent and good thermally conducting material. The mounting block **509** may also be of a good thermally conducting metal, such as copper or kovar, and has an opening through which the light from the microchip laser **510** can flow. The mounting plate **511** extends across, and is secured to, the front of the mounting block **509**. An optical filter **512** is. mounted across the front of the mounting plate **511**. A lens **513** is mounted in the opening **509***b* in the mounting block **509**.

In the operation of the optical device **500**, an electric current is applied across the VCSEL (array) to generate light in the active layer(s) **111**. The light is reflected back and forth in the active layer **111** between the first and second mirror stacks **106** and **113**. However, the first mirror stack **106** will partially allow light to pass therethrough, so that the generated light will be back-emitted from the VCSEL through the substrate **101**. The emitted beam of light is directed toward the doped glass laser disc **510** by way of lens **513**. Thus, the. light beam emitted by the VCSEL is focused onto the glass laser disc **510**, to thereby pump the glass laser disc **510** and cause it to generate and emit a beam of light.

Within the housing **501** and in front of the solid state microchip laser assembly **508** is an optical assembly **514**. Optical assembly **514** includes a tubular mount **515**, having an optical isolator **516** therein adjacent an end thereof, proximate to the assembly **508**. An optical collimating lens **517** is also mounted therein and is proximate to an opposing end of the tubular mount **515**. A photodiode **518** is in the wall of the mount **515** and is between the optical isolator **516** and the collimating lens **517**. A plug **519** is in the other end of the mount **518** adjacent the collimating lens **517**. Extending through the plug and mounted therein is a single mode optical fiber **520**. The inner end **521** of the optical fiber **520** is in alignment with the collimating lens **517**, so that it will receive light from the collimating lens **517** and serve as the output for the device **500**. The optical fiber **520** extends through and is secured in an opening in the front wall **505** of the housing **500**.

The beam of output light produced by the solid state laser disc **510**, which is of a wavelength different from the wavelength of the light emitted by the VCSEL **507**, is directed toward the filter **512**. Although most of the light from the VCSEL **507** pumps the laser glass disc **510**, some of the light from the VCSEL **507** passes through the glass disc **510** and is also directed toward the filter **512**. The filter **512** is designed to allow the light beam emitted by the solid state laser **510** to pass therethrough, but to block any light from the VCSEL **507**. Thus, only the light beam from the solid state laser **510** passes through the filter **512**.

The beam of light from the solid state laser **510** then enters the optical isolator **516**. The optical isolator **516** may be of any well-known construction which allows the beam of light from the solid state laser **510** to pass therethrough, but prevents any feedback of the light which may be reflected back by the other elements in the optical device **500**. The light beam passing through the optical isolator **516**, then enters the collimating lens **511**. The collimating lens **517** directs the beam of light into the inner end **521** of the optical fiber **520**. The light then passes out of the optical device **500** through the optical fiber **520** to carry out its desired purpose, such as for use in data communications or telecommunications. The photodiode **518** which is mounted in the mount **515** serves to monitor the output of the light beam emitted from the solid state microchip laser **510**.

Importantly, the VCSEL array described above, when used in conjunction with the laser system just described, permits significant reduction in the size and cost of the laser system as a whole, when compared to similar conventional laser systems. Particularly, the increased power of the beam output by the VCSEL array (resulting from the heat sink **118**) allows the use of VCSEL devices as laser pumps. As mentioned above, VCSEL devices are significantly cheaper, smaller and easier to produce than conventional pumping mechanisms. Furthermore, the use of integrated microlenses plays a role in reducing the size and cost of the laser system. In fact, the physical size of the VCSEL array, without the integrated microlenses discussed above, would present significant difficulties in implementation of a device similar to that shown in FIGS. **5** and **6**. That is, if an external lens (or lens system) having a sufficiently short focal length is used as lens **513**, collimation of the focused light proves difficult. If a longer focal length lens is used, collimation is improved; however, it becomes difficult to achieve a sufficiently small spot size at the glass laser disc **510**, because of the divergence of the emitted light beam. Thus, although the use of a VCSEL array that does not include integrated microlenses might be theoretically possible in a configuration similar to that illustrated in FIGS. **5** and **6**, such an implementation would be highly impractical in terms of size and difficulty.

These practical obstacles are easily overcome by the use of the VCSEL array having integrated microlenses described above. That is, the use of the disclosed array reduces or eliminates the need for arranging and using external lenses in pumping glass laser disc **510**, and thereby significantly improves the cost, size and quality of the device as a whole. Notably, the arrangement referred to above, wherein the array of refractive microlenses serves to converge the VCSEL array output beam, and each lens in lens system **513** is offset from the axis of an output beam of a corresponding single VCSEL device, is particularly desirable for effective pumping of the glass laser disc **510**.

Finally, referring to FIG. **7**, there is shown another embodiment of an optical device of the present invention, which is designated **700** and which is designed to provide a tunable output beam. The optical device **700** is similar to the optical device **500** shown in FIGS. **5** and **6** in that it includes a VCSEL **701**, which may be the same as the VCSEL **100** or the VCSEL array **300**/**400**. The device **700** also includes a focusing lens **702** for focusing the light from the VCSEL

701 onto a solid state laser disc **703**. The solid state laser disc **703** is similar to the solid state laser disc **510**, but has different optical coating characteristics on both of its surfaces, and is bonded on a good thermal dissipating substrate **704** mounted on heat conducting sub-mount **705**. Mounted in a mounting block **706** is an electrically or piezoelectrically driven thin etalon **707** or an electrically driven optical tunable filter. A laser output coupler **708** is also mounted on the mounting block **706**. Thus, the wide wavelength tunable laser is comprised of the laser glass gain medium disc **703**, such as erbium and ytterbium doped glass with suitable optical coatings on both surfaces, the wavelength selective device **707**, such as thin etalon or tunable filter, and the optical coupler **708**. The piezoelectrically driven thin etalon **707** or electrically driven tunable filter is adapted to provide wide wavelength tuning of the laser, in a wavelength range of, for example, 1530–1575 nm. The light from the output of the laser is directed into an optical fiber, not shown, in the same manner as shown in FIG. **5**. Also, the optical device **700** is mounted in a housing, not shown, as is shown in FIG. **5**.

Thus, there is provided by the present invention an optical device for providing a beam of light through an optical fiber for telecom or datacom purposes in which a VCSEL or a VCSEL array is used to pump a solid state laser. The solid state laser generates and emits a beam of light which is directed into the optical fiber. The VCSEL or VCSEL array includes a body of a semiconductor material mounted on a substrate, with the light generated in the semiconductor body being emitted through the substrate. The substrate has a lens or lens array formed along one surface which focuses/collimates the light emitted by the VCSEL. A heat sink, preferably of diamond or other good heat conducting material, is mounted on the side of the semiconductor body away from the substrate to conduct heat from the semiconductor body. The heat sink is mounted close to the portion of the semiconductor body in which the light is generated so as to provide improved cooling of the semiconductor body. This allows the VCSEL to be operated at higher bias to achieve greater power from the VCSEL.

Although the present invention has been described in conjunction with the above embodiments, it should be noted that these embodiments are designed only to illustrate, and not limit, the present invention.

What is claimed is:

1. A laser system comprising:

a VCSEL pump source; and

a doped-glass laser optically coupled with said VCSEL pump source to receive an output therefrom,

wherein the doped glass laser comprises a doped glass disk having a highly refelective mirror coating on a first face and a partially reflective coating on an opposing, output face, the highly reflective mirror faces the VCSEL pump source and is arranged to be transmitting at a wavelength of the VCSEL pump source.

2. A laser system in accordance with claim **1**, wherein said doped-glass laser is an Er:Yb doped-glass laser.

3. A laser system in accordance with claim **1**, further comprising:

a selecting means for selecting a desired wavelength of said output laser beam; and

an optical coupler which partially reflects and partially transmits said output laser beam.

4. A laser system in accordance with claim **3**, wherein said selecting means comprises an electrically or piezoelectrically-driven thin etalon.

5. A laser system in accordance with claim **3**, wherein said selecting means comprises an electrically driven optical tunable filter.

6. A laser system in accordance with claim **1**, wherein said VCSEL pump source comprises a VCSEL element.

7. A laser system in accordance with claim **6**, wherein said VCSEL element comprises:

a substrate having a microlens formed therein;

a first mirror region, formed on said substrate;

an active layer formed on said first mirror region;

a second mirror region formed on said active layer; and

a heat sink formed on said second mirror region.

8. A laser system in accordance with claim **7**, wherein said VCSEL element further comprises:

a contact layer on the second mirror region,

a metal layer on a surface of the heat sink facing the second mirror region; and

a bonding material which bonds the metal layer and the contact layer.

9. A laser system in accordance with claim **7**, wherein a material of said heat sink is diamond.

10. A laser system in accordance with claim **7**, wherein the microlens is a refractive or diffractive microlens, which reduces the divergence of the diode laser beam.

11. A laser system in accordance with claim **7**, wherein the microlens is a refractive or diffractive microlens, which focuses the diode laser beam.

12. A laser system in accordance with claim **1**, wherein the VCSEL pump source comprises a VCSEL array comprising a plurality of VCSEL elements arranged symmetrically on the substrate, each VCSEL element outputting an individual output laser beam so that the VCSEL array outputs a laser beam composed of individual output laser beams from said VCSEL elements, and further wherein each of said VCSEL elements comprises:

a substrate having a microlens formed therein;

a first mirror region, formed on said substrate;

an active layer formed on said first mirror region;

a second mirror region formed on said active layer; and

a heat sink formed on said second mirror region.

13. A laser system in accordance with claim **12**, wherein each microlens is a refractive microlens aligned on a primary axis of the individual output laser beams, and further wherein each microlens reduces the divergence of each of the individual output laser beams, to thereby reduce the divergence of the VCSEL pump source laser beam.

14. A laser system in accordance with claim **12**, wherein each microlens is a refractive microlens aligned on a primary axis of the individual output laser beams, and further wherein each microlens converges the individual output beams to a central point, to thereby focus the VCSEL pump source laser beam.

15. A laser system in accordance with claim **14**, further comprising external lenses which are offset from the primary axes of the individual output laser beams in a direction toward a center of the VCSEL array, to thereby progressively focus the VCSEL pump source laser beam.

16. A laser system in accordance with claim **12**, wherein each microlens is a refractive microlens aligned on a primary axis of the individual output laser beams, and further wherein the microlenses reduce the divergence of the composite output beam of the VCSEL array to less than 1°, and thereby collimate the diode laser beam.

17. A laser system in accordance with claim **1**, wherein said VCSEL pump source comprises a plurality of VCSEL elements arranged in a VCSEL array.

18. A method for generating and emitting a laser beam, comprising:

generating a pump laser beam within a VCSEL pump source;

emitting the pump laser beam from the VCSEL pump source through a microlens which is integrated within a substrate of the VCSEL pump source;

focusing the pump laser beam onto a doped-glass laser with a lens system which comprises the microlens;

pumping said doped-glass laser with said pump laser beam;

generating an output laser beam within said doped-glass laser; and

emitting said output laser beam,

wherein the doped glass laser is a doped glass disk having a highly refelective mirror coating on a first face and a partially reflective coating on an opposing, output face, the highly reflective mirror faces the VCSEL pump source and is arranged to be transmitting at a wavelength of the VCSEL pump source.

19. A tunable laser, comprising:

a semiconductor pump laser;

a laser output coupler disposed proximate said semiconductor pump laser;

a solid laser gain medium disposed between said semiconductor pump laser and said output coupler; and

a tunable wavelength selective device disposed between said solid laser gain medium and said laser output coupler,

wherein the solid laser gain medium is a doped glass disk having a highly reflective mirror coating on a first face, the highly reflective mirror faces the semiconductor pump laser and is arranged to be transmitting at the wavelength of the semiconductor pump laser,

wherein said semiconductor pump laser pumps said solid laser gain medium substantially along a path coinciding with a light output path, from a side opposed to said light output side.

20. A method for generating a beam of light, comprising:

pumping a solid laser gain medium with a VCSEL pump source along a pump direction, said gain medium being disposed within a laser resonant cavity; and

selecting an output wavelength from a range of wavelengths from said laser resonant cavity,

wherein said beam of light generated is substantially co-linear with said pump direction, on an opposing side of said solid laser gain medium, and

wherein a tunable wavelength selective device is disposed in the resonant cavity, the tunable wavelength selective device is constructed to restrict the laser output to a wavelength from said laser cavity.

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